Patent Claims

1. A refractive projection objective for imaging a pattern, arranged in an object plane of the projection objective, into an image plane of the projection objective with the aid of an immersion medium that is arranged between a last optical element of the projection objective and the image plane, comprising
a first lens group (LG1) following the image plane and of negative refractive power;
a second lens group (LG2) following the first lens group and of positive refractive power;
a third lens group (LG3) following the second lens group and of negative refractive power;
a fourth lens group (LG4) following the third lens group and of positive refractive power;
a fifth lens group (LG5) following the fourth lens group and of positive refractive power; and
a system diaphragm (5) that is arranged in a transition region from the fourth lens group to the fifth lens group,
wherein the fourth lens group has an entrance surface (E) that lies in the vicinity of a point of inflection of a marginal ray height between the third lens group (LG3) and the fourth lens group (LG4), and no negative lens of substantial refractive power is arranged between the entrance surface and the system diaphragm (5).

2. The projection objective as claimed in claim 1, wherein only positive lenses are arranged between the entrance surface (E) and the system diaphragm (5).

3. The projection objective as claimed in claim 1 or 2, wherein the fifth lens group (LG5) has exclusively lenses of positive refractive power.

4. The projection objective as claimed in one of the preceding claims, wherein a waist (X) of minimal beam

diameter exists in the region of the third lens group (LG3), and a lens pair (20, 21, 120, 121, 220, 221, 320, 321) having lenses immediately following one another and for which $\phi_i * \phi_{i+1} < 0$ exists between this waist and the image plane (3) at only one location, ϕ_i and ϕ_{i+1} being the refractive powers of the lenses of the lens pair, and $|\phi_i| > 0.12\ m^{-1}$.

5. The projection objective as claimed in one of the preceding claims, wherein lens pairs having lenses immediately following one another and for which $\phi_i * \phi_{i+1} < 0$ exists between the object plane and the image plane only at three locations, ϕ_i and ϕ_{i+1} being the refractive powers of the lenses of the lens pair, and it being preferred that $|\phi_i| > 0.12\ m^{-1}$.

6. The projection objective as claimed in one of the preceding claims, wherein the first lens group (LG1) includes at least one aspheric surface, at least two aspheric surfaces preferably being provided in the first lens group.

7. The projection objective as claimed in one of the preceding claims, wherein the first lens group (LG1) includes at least two lenses each having one aspheric surface.

8. The projection objective as claimed in one of the preceding claims, wherein there is arranged in a first lens region (LB1) in which the principal ray height is large as against the marginal ray height, at least one aspheric surface that has a curvature which has at most one point of inflection in an optically useful range, preferably two such surfaces being provided.

9. The projection objective as claimed in one of the preceding claims, wherein not more than three aspheric surfaces having one or more points of inflection are arranged in the first lens region (LB1).

10. The projection objective as claimed in one of the preceding claims, wherein the aspheric surfaces of a first lens region (LB1) fulfill the condition $|\Sigma C1_i| * 10^6 > 0.22$, $C1_i$ being the coefficient of the term h^4 of the aspheric surface representation of the ith surface.

11. The projection objective as claimed in one of the preceding claims, wherein a number of aspheric surfaces with an optically useful diameter of more than 20% of an overall length of the projection objective are concave, preferably all of the aspheric surfaces with an optically useful diameter of more than 20% of an overall length of the projection objective being concave.

12. The projection objective as claimed in one of the preceding claims, wherein there are arranged in a second lens region (LB2), which extends between the object plane (2) and a region in which a principal ray height corresponds substantially to a marginal ray height, at least two aspheric surfaces whose aspheric contributions to the distortion are of opposite signs.

13. The projection objective as claimed in one of the preceding claims, wherein at least one aspheric surface is provided in the third lens group (LG3), preferably two aspheric surfaces being provided.

14. The projection objective as claimed in one of the preceding claims, wherein at least one aspheric surface is arranged in each lens group.

15. The projection objective as claimed in one of the preceding claims, wherein at least two aspheric surfaces have a deformation of more than 1.2 mm relative to an assigned enveloping sphere.

16. The projection objective as claimed in one of the preceding claims, wherein the condition 0.9 * PSA31 < PSA3 < 1.1 * PSA31 is fulfilled for the spherical pupil aberration PSA, PSA31 being the sum of the aberration coefficients of the spherical pupil aberration of all the surfaces within a first lens region (LB1), and PSA3 being the sum of the aberration coefficients of the spherical pupil aberration of all the surfaces of the system.

17. The projection objective as claimed in one of the preceding claims, which has an object/image distance L and a focal length f' and is adapted to an immersion medium with a refractive index n_I, the following condition being fulfilled: $L/f' * n_I > 2.5$.

18. The projection objective as claimed in one of the preceding claims, wherein the system diaphragm (5) has a diaphragm edge that determines the diaphragm diameter and whose axial position with reference to the optical axis of the projection objective can be varied as a function of the diaphragm diameter.

19. The projection objective as claimed in one of the preceding claims, wherein the system diaphragm is designed as a spherical diaphragm or as a conical diaphragm.

20. The projection objective as claimed in one of the preceding claims, wherein the system diaphragm is axially displaceable.

21. The projection objective as claimed in one of the preceding claims, wherein there is provided in a transition region from the third lens group (LG3) to the fourth lens group (LG4) at least one lens doublet (20, 21, 120, 121, 220, 221, 320, 321) that comprises a negative lens of weakly refractive power and a positive lens following directly in the transmission direction,

the negative lens having an image-side concave surface, and the subsequent positive lens having an object-side concave surface.

22. The projection objective as claimed in claim 21, wherein the positive lens (21, 121, 221, 321) is a positive meniscus lens that is concave relative to the object plane and has an entrance-end lens radius R1 and an exit-end lens radius R2, and fulfills the following condition: $(R1 + R2)/(R1 - R2) < -1.5$.

23. The projection objective as claimed in one of claims 21 or 22, wherein mutually facing concave surfaces of the lens doublet are aspheric.

24. The projection objective as claimed in one of the preceding claims, wherein at least one meniscus lens (124, 324', 424) that is concave relative to the object plane and fulfills the condition $D_L/D_{min} > 1.3$ is arranged in the fourth lens group (LG4), D_{min} being the smallest light pencil diameter in the fourth lens group and D_L being the maximum light pencil diameter in the meniscus lens.

25. The projection objective as claimed in one of the preceding claims, wherein all the lenses consist of the same material, synthetic quartz glass preferably being used as lens material for a 193 nm operating wavelength, and/or calcium fluoride preferably being used as lens material for a 157 nm wavelength.

26. The projection objective as claimed in one of the preceding claims, wherein a predominant number of lenses consists of synthetic quartz glass, at least two of the lens elements arranged in the immediate vicinity of the image plane consisting of a fluoride crystal material of the same crystal orientation.

27. The projection objective as claimed in one of the preceding claims, wherein a predominant number of lenses consists of synthetic quartz glass, at least one positive lens made from a fluoride crystal material being provided in the second lens group (LG2).

28. The projection objective as claimed in one of the preceding claims, wherein a predominant number of lenses consists of synthetic quartz glass, at least one positive lens made from fluoride crystal material being provided in the fourth lens group.

29. The projection objective as claimed in one of the preceding claims, wherein a predominant number of lenses consists of synthetic quartz glass, at least one negative lens of the third lens group consisting of fluoride crystal material.

30. The projection objective as claimed in one of the preceding claims, which has an image-side numerical aperture NA ≥ 0.98, the image-side numerical aperture preferably being at least NA = 1.0 or at least NA = 1.1.

31. The projection objective as claimed in one of the preceding claims, wherein the projection objective is adapted to an immersion medium (10) that has a refractive index n > 1.3 at an operating wavelength.

32. The projection objective as claimed in one of the preceding claims, wherein the projection objective has an image-side working distance of at least one millimeter, the image-side working distance preferably being between approximately 1 mm and approximately 15 mm, in particular between approximately 1.5 mm and approximately 10 mm.

33. The projection objective, in particular as claimed in at least one of the preceding claims, the projection

objective having an object-side working distance that is smaller than 20 mm, in particular smaller than 10 mm.

34. The projection objective, in particular as claimed in at least one of the preceding claims, wherein the projection objective has an object-side working distance that is smaller than 50%, in particular smaller than 25%, of the object field diameter.

35. The projection objective, in particular as claimed in at least one of the preceding claims, wherein the projection objective has an object-side working distance that lies between approximately 5 mm and approximately 25% of the object field diameter.

36. The projection objective as claimed in at least one of claims 33 to 35, wherein the projection objective has an image-side numerical aperture NA > 0.8.

37. The projection objective as claimed in one of the preceding claims, wherein the second lens group (LG2) has at least four, preferably at least five consecutive lenses of positive refractive power.

38. The projection objective as claimed in one of the preceding claims, wherein on an entrance side facing the object plane (2) the second lens group (LG2) has at least one, preferably a plurality of meniscus lenses, concave relative to the object plane, of positive refractive power and/or, on the exit side facing the image plane, the second lens group having at least one, preferably a plurality of meniscus lenses, convex relative to the object plane, of positive refractive power.

39. The projection objective as claimed in one of the preceding claims, wherein the second lens group (LG2)

in this sequence has at least one meniscus lens, concave relative to the object plane, of positive refractive power, a biconvex positive lens and at least one meniscus lens, concave relative to the image plane, of positive refractive power.

40. The projection objective as claimed in one of the preceding claims, wherein the third lens group (LG3) has only lenses of negative refractive power.

41. The projection objective as claimed in one of the preceding claims, wherein in an object-side entrance region the fourth lens group (LG4) has at least one meniscus lens, concave relative to the object plane (2), of positive refractive power, preferably a number of such meniscus lenses being provided consecutively.

42. The projection objective as claimed in one of the preceding claims, wherein the fifth lens group (LG5) has at least one meniscus lens of positive refractive power and lens surfaces that are concave toward the image.

43. The projection objective as claimed in one of the preceding claims, wherein the fifth lens group (LG5) has as last optical element a planoconvex lens that preferably has a spherical or aspherically curved entrance surface and a substantially flat exit surface.

44. The projection objective as claimed in claim 43, wherein the planoconvex lens is of non-hemispherical design.

45. The projection objective as claimed in one of the preceding claims, which is a one-waist system having a belly (6) near the object, a belly (8) near the image and one waist (7) lying therebetween.

46. The projection objective as claimed in one of the preceding claims, wherein a maximum marginal ray height is at least twice as large as the marginal ray height at the location (X) of the narrowest constriction.

47. The projection objective as claimed in one of the preceding claims, wherein a belly (6) near the object has a first belly diameter, and a belly (8) near the image has a second belly diameter, and wherein a belly diameter ratio between the second and the first belly diameters is more than 1.1, in particular more than 1.2.

48. The projection objective as claimed in one of the preceding claims, wherein the image plane follows directly after the fifth lens group such that apart from the first to fifth lens group the projection objective has no further lens or lens group.

49. A projection exposure machine for microlithography characterized by a refractive projection objective as claimed in one of the preceding claims.

50. A method for producing semiconductor components and other finely structured components, having the following steps:
providing a mask with a prescribed pattern;
illuminating the mask with ultraviolet light of a prescribed wavelength;
imaging an image of the pattern onto a photosensitive substrate, arranged in the region of the image plane of a projection objective, with the aid of a projection objective in accordance with one of the preceding claims 1 to 44;
an immersion medium arranged between a last optical surface of the projection objective and the substrate being transirradiated during projection.